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(54) **METHOD AND APPARATUS FOR MALDI ANALYSIS**

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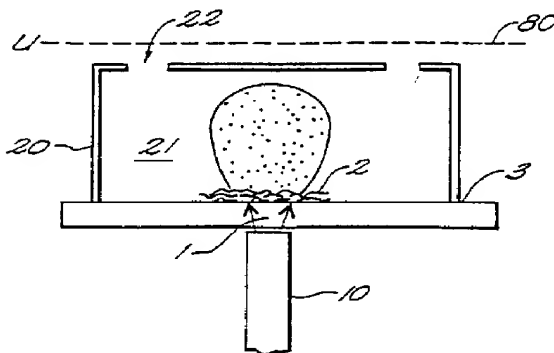**G. Scott Higgins,** Glasgow (GB); **Dirk Reuter,** Norderstedt (DE)
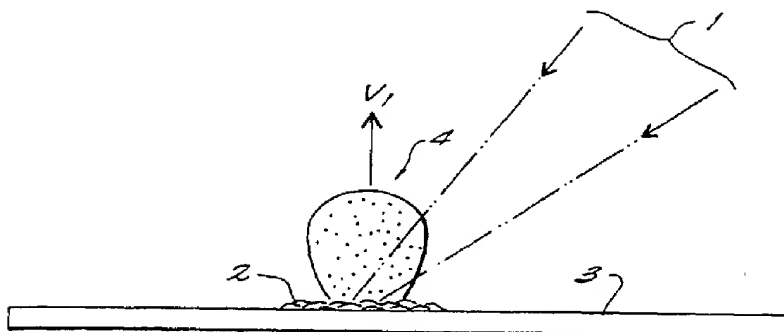
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(63) Continuation of application No. 09/483,629, filed on Jan. 14, 2000. Continuation of application No. 08/934,455, filed on Sep. 19, 1997, now Pat. No. 6,111,251. Continuation-in-part of application No. 08/710,565, filed on Sep. 19, 1996, now Pat. No. 5,777,324.

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(57) **ABSTRACT**

Matrix assisted laser desorption/ionization (MALDI) is performed in a manner that thermalizes large analyte ions in a plume of desorbed material for spectroscopic analysis. The thermalized ions have a low or zero mean velocity and are presented at a well-defined instant in time, reducing artifacts and sharpening the spectral peaks. In one embodiment the light is delivered to a matrix or sample holder having a cover, baffle or compartment. The baffle or compartment impedes or contains a plume of desorbed material and the analyte undergoes collisions to lower its mean velocity and directionality. Thus "thermalized" the analyte ions are passed to a mass analysis instrument.
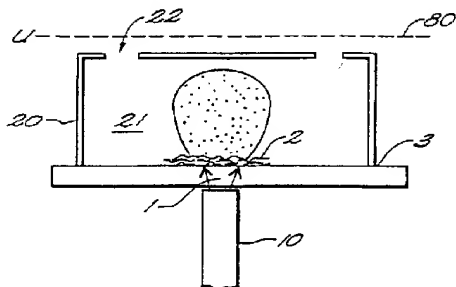
FIG. 1

ILLUMINATE SAMPLE
TO DESORB MATERIAL

COLLISION-THERMALIZE
DESORBED MATERIAL

INITIATE SEPARATION
ANALYSIS
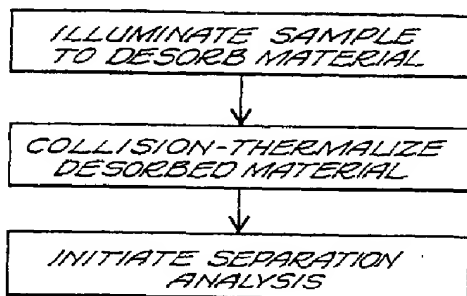
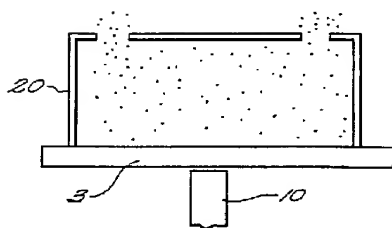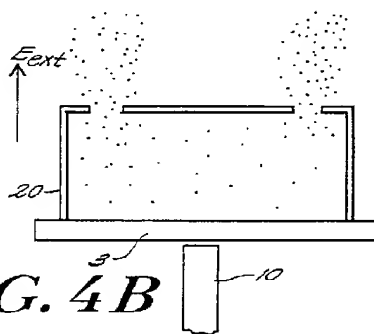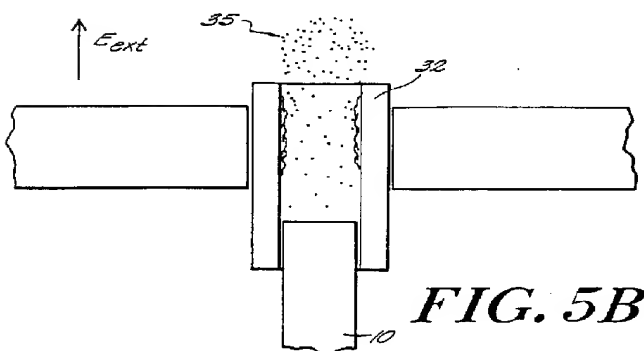# FIG. 2

FIG. 3A
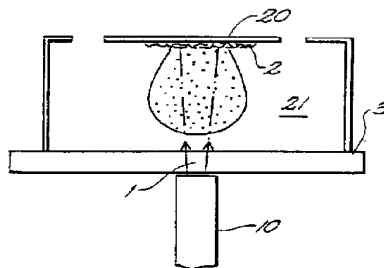
FIG. 3B

FIG. 4A

FIG. 4B

FIG. 5A

FIG. 5B
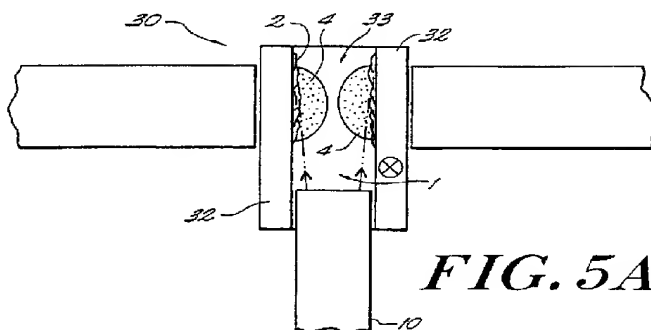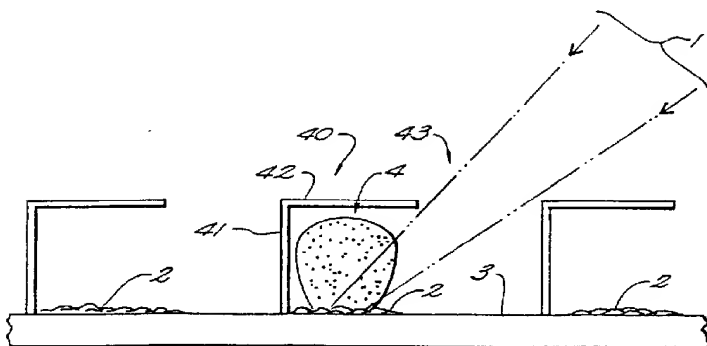
FIG. 6A
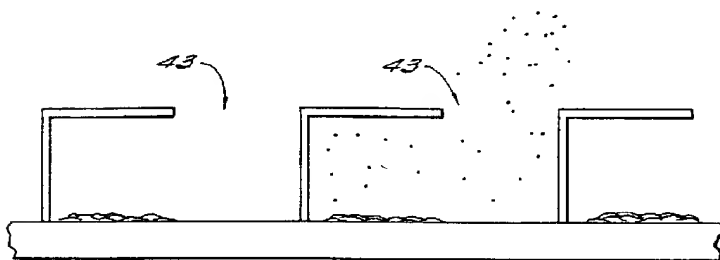
FIG. 6B
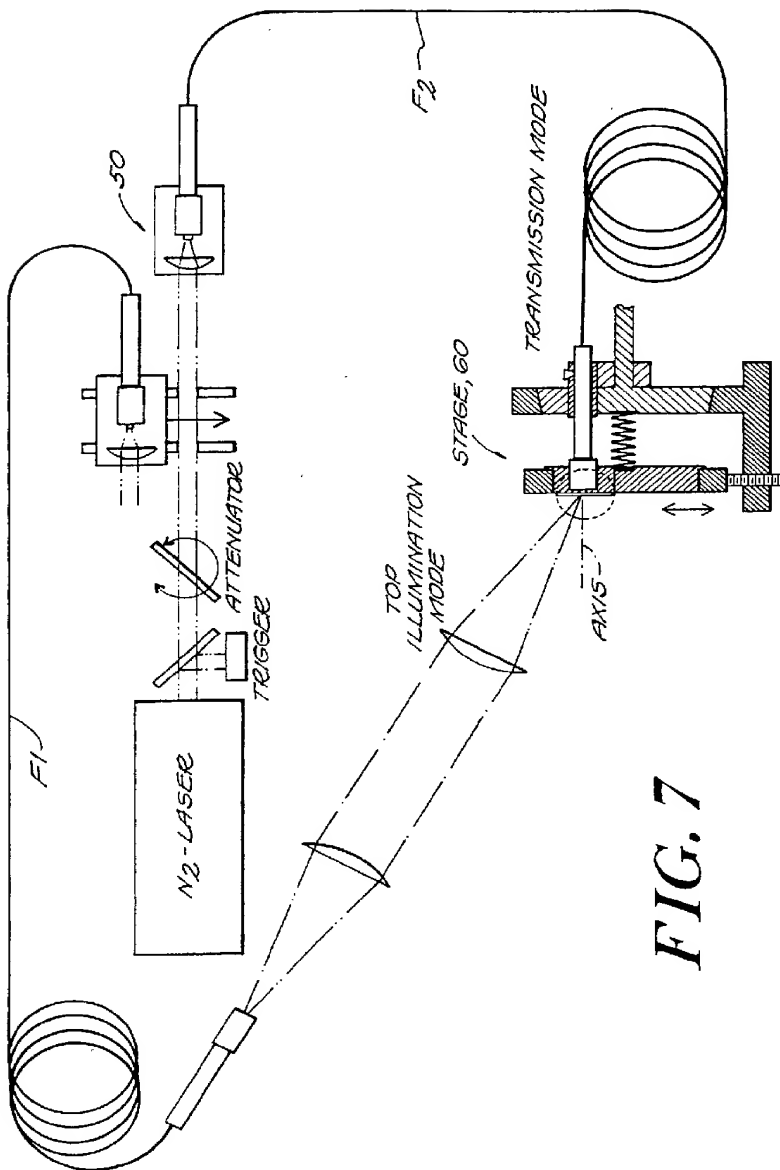
FIG. 7

FIG. 7A

FIG. 8A

FIG. 8B

FIG. 9A

FIG. 9B
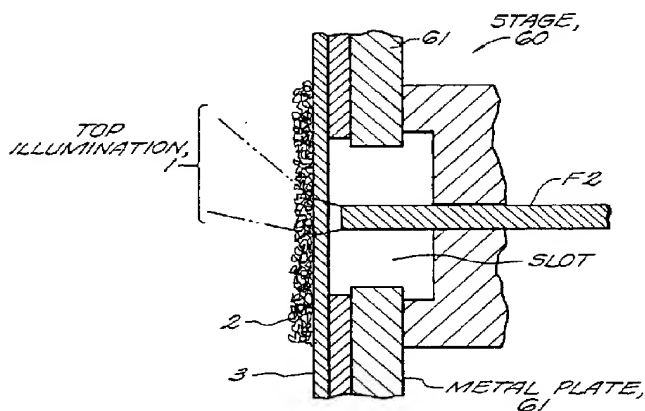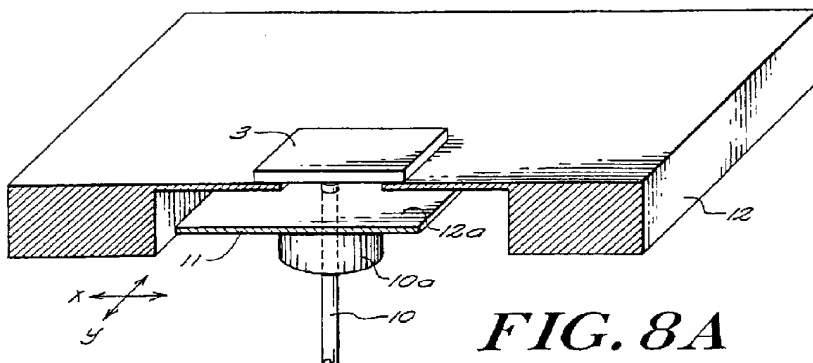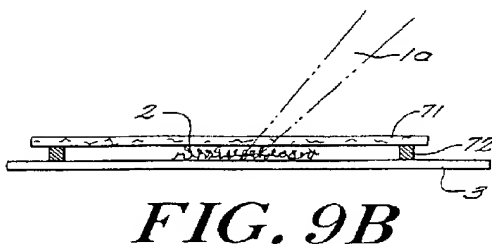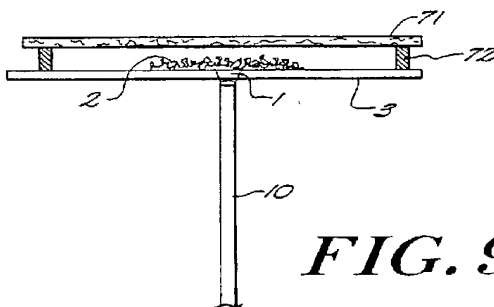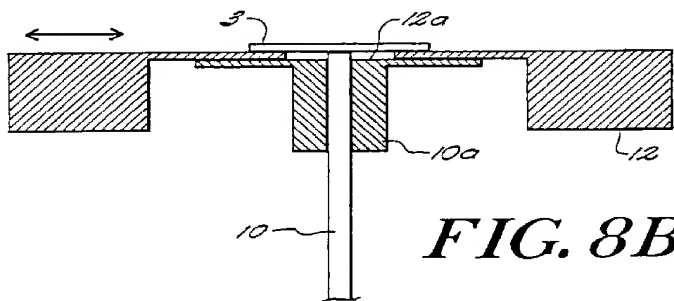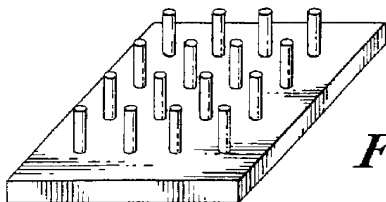
FIG. 10
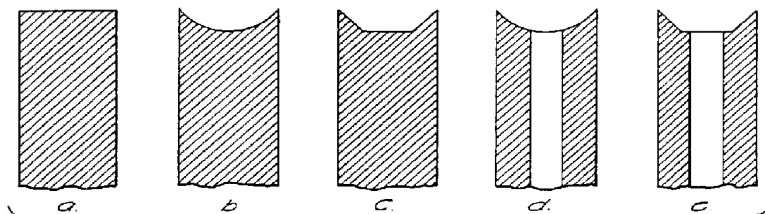
FIG. 11
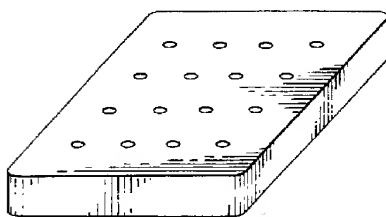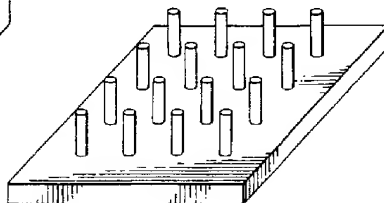
FIG. 12A   FIG. 12B
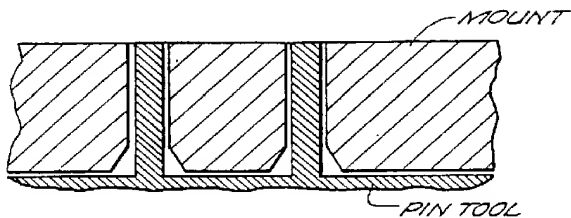
FIG. 12C
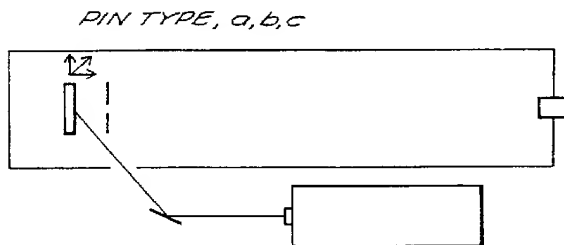
FIG. 13
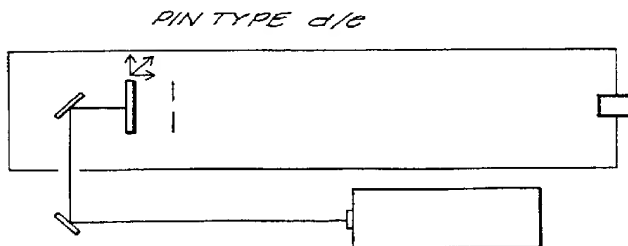
FIG. 13A
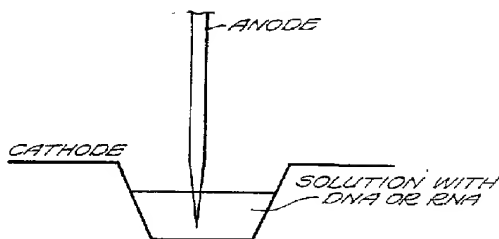
FIG. 14

Experimental flow diagram:

PCR: 50μl volume (3' modified primers)
⇩
Addition of functionalised beads, incubation, capture of unused primers
⇩
Aliquot PCR reaction to sequencing mixes (A,C,G,T)
⇩
Aliquot sequencing mix into sequencing plate (192/384-well, 48/96 seq. R_xn's)
⇩
Addition of sequencing primer(s), 5' modified to allow capture
⇩
Cycle sequencing reaction: 10μl volume
⇩
Application of pin tool, capture of sequencing products
⇩
Wash steps (3 x NH_4Cit)
⇩   ⇩
Addition of matrix   Removal to chips
⇩
Addition of matrix
⇩
Mass spectrometry

FIG. 15

METHOD AND APPARATUS FOR MALDI ANALYSIS

RELATED APPLICATIONS

[0001]   This application is a continuation of U.S. application Ser. No. 09/483,629, filed Jan. 14, 2000. This application is also continuation of allowed U.S. application Ser. No. 08/934,455, filed Sep. 19, 1997, now U.S. Pat. No. 6,111, 251, and is also a continuation-in-part of U.S. application Ser. No. 08/710,565, filed Sep. 19, 1996, now U.S. Pat. No. 5,777,324, each of which is incorporated herein by reference in its entirety.

FIELD OF INVENTION

[0002]   The present invention relates to Matrix Assisted Laser Desorption/Ionization Mass Spectrometry (MALDI-MS).

BACKGROUND

[0003]   Matrix Assisted Laser Desorption/Ionization Mass Spectrometry (MALDI-MS) was introduced by Karas and Hillenkamp in 1988 and has become established as a method for mass determination of biopolymers and substances such as peptides, proteins and DNA fragments. In this method, the substance to be analyzed is typically placed in a solution of matrix material and coated onto a support. The solute evaporates, leaving the analyte in a solid matrix which is then illuminated to cause the analyte molecules or synthetic polymers to be desorbed. This desorption process is especially useful for releasing large biological molecules without charring, fragmentation or chemical degradation to a mass spectrometer or similar instrument for separation and detection.

[0004]   In common MALDI mass spectrometry setups, the sample is placed on a metal substrate and is irradiated from the side facing the ion analyzer ("top illumination"). In contrast to this arrangement, transmission illumination is also possible wherein the rear side of the sample is illuminated through a transparent substrate, for example by a focused laser beam. In either event, the matrix consisting of a relatively low molecular weight aromatic organic substance such as nicotinic acid, benzoic or cinnamic acid, holds a quantity of the peptide, protein or other substance to be analyzed and is irradiated with a high intensity laser beam to cause desorption of the analyte from a surface of the sample. In a representative mass spectrometry arrangement, ions of the analyte are subjected to electric field acceleration for mass separation in the instrument, such as a time-of-flight (TOF) mass spectrometer. The laser radiation is selected such that matrix strongly absorbs at the laser wavelength and desorbs material sufficiently quickly to form an ejecting plume at its outer surface. The laser wavelength, however, is sufficiently long to not break bonds of the analyte, and the desorption process is non-thermal so that large molecules are provided to the spectrometer instrument substantially intact. The mechanism of desorbing or ejecting large molecules from a relatively light matrix material is quite general, and allows one to detect analytes having a mass of tens or hundreds of kiloDaltons. Various techniques for preparing certain classes of substances for desorption from a variety of matrix materials have extended the usefulness of the technique.

[0005]   In conventional instruments, the standard configuration involves performing both illumination and mass analysis from the same side of the sample. This produces a relatively high yield of large molecule ions and good mass resolution. Illumination spot sizes of between 50 and 1000 micrometers in diameter have been used with illumination levels in the range of 10^6-10^7 watts/square centimeter to essentially eject small volumes of the sample and provide a short, high velocity plume of material for analysis. An extensive library of organic large molecule spectra has been built up using such instruments. Nonetheless, the geometrical requirements of providing an ion extraction and acceleration optics in a vacuum flight chamber with a number of high voltage electrodes to accelerate the material to an analysis detector impose constraints on the optical path of the laser illumination beam, resulting in a relatively costly and inflexible instrument. Furthermore, the provision of a relatively high energy plume as the initial ion source results in a spread of velocities and spatial position of the initial burst of ions, which in addition are subject to differing electric fields because of the spatial spread of the plume, so that, while the instrument provides a good yield of analyte, the mass resolution is compromised. In general, the matrix molecules provide an internal reference peak. However, since the analyte is often many times greater in mass, and mechanism of desorption is also not fully understood, it is also possible that the acquired spectra include unrecognized shifts and other artifacts resulting from initial plume geometry or release dynamics that will complicate the accuracy of mass determination and a comparison with independently produced spectra in the future.

[0006]   Various researchers have explored transmission MALDI for different materials and one or more matrix compositions, and have been able under some conditions to obtain results analogous to those accumulated using the more prevalent top side illumination. In general, by separating illumination and the mass analysis instrumentation on opposite sides of a matrix one might expect to implement different instrument designs with greater freedom. In particular, scanning arrangements might be implemented to allow the selective analysis of particular spots or sample locations. Furthermore, the ability to provide ion desorption from a defined surface may be expected to yield sharper spectra. However in switching from a top illumination configuration to a transmission illumination configuration, one of necessity changes the nature of a number of essential processes underlying the desorption technique. Thus for example the shape of the plume, the velocities or directions of molecules or ions upon release, and the underlying mechanism or yield of the release may all be affected by a change in the illumination/desorption geometry. Relatively few experiments have utilized transmission illumination, and these have in general yielded lower quality spectra than top illumination, and have been tried only with a limited range of relatively light analyte molecules.

[0007]   The essential mechanisms by which material is desorbed are not fully understood, and effects may vary with different materials. In general, to make a measurement one tunes the analyzer by setting appropriate electric and/or magnetic fields, or otherwise defining a sample window, then illuminates the matrix, progressively increasing the fluence until the spectrometer starts to detect desorbed ions. The fluence may generally then be increased somewhat to increase the amount of the heavy analyte present in the

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desorbed material, but should not be increased so much as to introduce charring or fragmentation of the material. In general, increase in illumination fluence increases the amount of material released. However, as described above, the mass resolution, which is initially limited, may suffer due to an increased spread of initial velocities, the irregular geometry of the emission plume or other factors.

[0008] It is therefore desirable to provide a transmission MALDI method or apparatus in which resulting spectra are identical to or well correlated with MALDI spectra obtained in top illumination of similar compounds.

[0009] It is also desirable to provide new transmission MALDI stages or mechanisms for desorption of an analysis sample.

[0010] It is also desirable to provide a MALDI spectrometry process wherein the peaks are improved, and mass resolution refined.

SUMMARY

[0011] One or more of the above desirable ends are achieved in accordance with the present invention by carrying out matrix assisted laser desorption analysis in a manner to inject analyte ions into a spectrometric analysis system with a low or zero mean velocity at a defined instant in time. Matrix assisted laser desorption/ionization is performed in a manner to thermalize large analyte ions in a plume of desorbed material for spectroscopic analysis. The thermalized ions have a low or zero mean velocity and are presented at a well-defined instant in time, reducing artifacts and sharpening the spectral peaks. In one embodiment the light is delivered to a matrix or sample holder having a cover, baffle or compartment. The baffle or compartment impedes or contains a plume of desorbed material and the analyte undergoes collisions to lower its mean velocity and directionality. Thus "thermalized" the analyte ions are passed to a mass analysis instrument. In another embodiment an optical fiber butts up against a thin transparent plate on which the specimen resides, with the matrix side in a vacuum acceleration chamber. A mechanical stage moves the specimen in both the x- and y- directions to select a point on the specimen which is to receive the radiation. The use of a fiber optic illuminator allows the entire stage assembly to be subsumed essentially within the dimensions of a conventional stage. In other embodiments, a thermalizing compartment is provided in a capillary tube about the end of the illumination fiber and the sample matrix is deposited along the inner cylindrical wall of the tube, so the capillary forms a migration path to the outlet for thermalization of the desorbed analyte. In other embodiments microstructures having the shape of a small lean-to, overhang or perforated cover plate, or providing a high aspect surface texture, provide the necessary containment to promote thermalization of the released analyte. A thin layer or cover of fibrous or permeable material may also be used to thermalize the analyte before mass analysis, and in other embodiment this material may also act as the substrate. An automated instrument may include a fixed array of illumination fibers which are illuminated at different times to eject samples from a corresponding array of points on the specimen. In one embodiment the laser light is delivered to a matrix or sample holder having a cover, baffle or compartment. The laser illuminates the matrix, preferably over a relatively large spot

at a fluence in the range of 10^6 watts/square centimeter, causing the desorption of analyte and matrix material which is released in a plume. The baffle or compartment impedes or contains the plume to instantaneously define a region with a relatively high density of analyte and matrix. The analyte, which may have a molecular weight tens to thousands of times greater than the matrix, undergoes collisions to achieve a mean velocity which is low or zero. Thus "thermalized" the analyte ions are passed from the baffle region to undergo a conventional mass analysis.

[0012] In a preferred embodiment of a stage useful for the practice of the invention, the laser illumination is provided by the output end of an optical fiber which may for example receive illumination at its input end from a gas laser, a hybrid frequency-multiplying laser arrangement, a high powered laser diode array, or a diode-pumped source. The end of the optical fiber butts up against a thin transparent plate on which the sample reside, the sample being on the side of the plate opposite the fiber facing in a vacuum acceleration chamber. Preferably, a mechanical stage moves the plate in both the x- and y- in-plane directions to select a sample or a point on a given sample which is to receive the radiation. The use of a fiber optic illuminator allows the entire stage assembly to be subsumed essentially within the dimensions of a conventional instrument stage yet provide a robust and accurate illumination source of well defined intensity and high uniformity. Emission from the source then illuminates the sample, causing the analyte to be desorbed at a surface of the plate facing the mass analyzer assembly. In accordance with one aspect of the invention the plume is partially confined so that its highly directional momentum is randomized, or "thermalized". After thermalizing, the plume environment contains slow ions which are accelerated in the analyzer, separating each characteristic charge/mass component into a sharply defined interval for spectrometric detection.

[0013] In other embodiments, a thermalizing region is defined by a small ferrule or capillary-like tube enclosure which surrounds a region at the end of the illumination fiber. The matrix is deposited along the inner cylindrical wall of the tube, where the divergent fiber output illuminates the matrix. The tube provides a short tunnel as a migration path to the outlet in which the desorbed material is initially ejected with oblique paths for thermalization of the desorbed analyte. In other embodiments microstructures having the shape of a small lean-to, overhang or perforated cover plate provide containment to increase residence time or provide collisional interaction for thermalization of the released analyte. Such a confining microstructure can also be formed by the sample crystals and the surface of the substrate if the crystallization process is specifically controlled to achieve such structures.

[0014] The latter constructions may include a two stage release configuration wherein the laser illumination forms a plume which then fills a compartment. The compartment has an opening in one wall through which the thermalized ions which have migrated from the illumination plume are emitted. In this two-stage construction, the distance between illumination and outlet is made large enough to thermalize the large molecules, but small enough to assure that emission of analyte ions occurs in a short time interval that does not broaden the TOF peak width.

BRIEF DESCRIPTION OF THE DRAWINGS

[0015] These and other features of the invention will be understood from the description of representative embodiments of the method herein and the disclosure of illustrative apparatus for carrying out the method, taken together with the Figures, wherein

[0016] **FIG. 1** illustrates a prior art MALDI analysis technique;

[0017] **FIG. 2** illustrates steps of MALDI analysis in accordance with the present invention;

[0018] **FIGS. 3A and 3B** illustrate a basic embodiment of an apparatus in accordance with the present invention for two different sample mounts for a transmission MALDI analysis, respectively;

[0019] **FIGS. 4A and 4B** illustrate stages of operation of the embodiment of **FIGS. 3A** or **3B**;

[0020] **FIGS. 5A and 5B** illustrate a second embodiment and its operation;

[0021] **FIGS. 6A and 6B** illustrate a third embodiment and its operation for top illumination;

[0022] **FIGS. 7 and 7A** illustrate an experimental MALDI set up;

[0023] **FIGS. 8A and 8B** show a preferred stage for practice of the invention;

[0024] **FIGS. 9A and 9B** illustrate a fourth embodiment of the invention;

[0025] **FIG. 10** schematically depicts a pin tool apparatus;

[0026] **FIG. 11** depicts various pin conformations. **FIGS. 11A** shows a solid pin with a straight head. **FIG. 11B** shows a solid pin with a concave head. **FIG. 11C** shows a solid pin with a truncated pyramidal head. **FIG. 11D** shows a pin with a concave head and a hollowed center (through which can be inserted an optical fibre). **FIG. 11E** shows a pin with a truncated pyramidal head and hollowed center.

[0027] **FIGS. 12A-C** schematically represent a pintool apparatus and mount, each separately and a cross section of the mount and tool installed.

[0028] **FIG. 13** and **FIG. 13A** show a schematic representation of mass spectrometry geometries for the pintools shown in **FIG. 10**, **FIG. 11A-E**, and **FIG. 12B**.

[0029] **FIG. 14** schematically depicts a pintool onto which a voltage is applied. When an electrical field is applied, nucleic acids are attracted to the plate. This system would also purify nucleic acids, since uncharged molecules would remain in solution, while positively charged molecules would be attracted towards the cathode.

[0030] **FIG. 15** shows a flow chart of the steps involved in sequencing by mass spectrometry using post-biology capture.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENTS

[0031] **FIG. 1** shows a representative prior art set up for the matrix assisted laser desorption and ionization of a specimen such as a large molecule compound having a molecular weight, for example, in the range of 500 to

100,000 daltons or more. As shown, a substrate **3** such as a sheet of metal foil or a glass slide, bears a sample **2** in a region on its surface. As discussed above, sample **2** is generally deposited as a solution of a relatively low molecular weight laser-absorbent material with a minor amount of the large molecule analyte contained therein, and it is allowed to dry in place to form a thin layer of solid material which may for example consist of a granular or continuous bed of crystals. In special cases a solvent, stable in vacuo is used such as glycerol. The sample **2** then forms a thin liquid layer or droplet on substrate **3**. A laser beam **1** is directed at the sample **2** causing a plume **4** of material to be desorbed therefrom. In general, the matrix material is taken to be a low molecular weight compound, e.g. an aromatic compound for desorption with wavelengths in the ultraviolet (UV), and the laser has a wavelength selected to excite and be strongly absorbed by the matrix material. Illumination of the sample then results in desorption of material therefrom and formation of a plume **4** which expands away from the illuminated site as shown in this figure. While the mechanism of large molecule desorption is not fully understood, it is clearly different from a "thermal" evaporation and it is a very fast event; the analyte therefore enters the surrounding vacuum chamber without extensive chemical degradation. However, as further illustrated in **FIG. 1**, the desorbed material is highly directional, having a large component of velocity in the direction normal to the surface indicated by vector V_1 in the figure. The plume expansion velocity is typically on the order of 500 to 1,000 meters per second.

[0032] In a typical analysis process, the desorbed material in plume **4** is provided to a mass spectrometer such as a sector or quadrupole scanning spectrometer which provides both acceleration and a mass-dependent transmission from, or to a time of flight (TOF) mass analyzer. Generally a time of flight instrument is preferred since the relatively small amount of sample in the plume results in a very low collection efficiency, poor sensitivity and difficulty in setting up for a sector scanning instrument.

[0033] For a time of flight instrument, the kinetics of molecular transport may be roughly modeled based on certain assumptions about the nature of the plume, the geometry of the plume generation stage, and surrounding electrodes and field strengths. When setting up such a model, the mass resolution, $m/\Delta m$, may, with the initial velocity and certain simplifying assumptions, be approximated as the magnitude of a sum of terms, including a term varying with the initial velocity spread and plume extent in relation to electrode spacing. Basically, initial velocity (energy) spread, the extent to which the plume subjects molecules to different field conditions, and the extent to which the ions undergo collisions or experience a turnaround time in the desorption and acceleration geometry, all introduce a spreading in the time of arrival peaks at the detector.

[0034] These problems are addressed in accordance with a principal aspect of the present invention by a method for the laser desorption and ionization of a sample as set forth in **FIG. 2**. In general, the sample consists of a solid matrix including the analyte material to be measured, and is deposited on a support for illumination by a laser, substantially as in the prior art. As set forth in **FIG. 2** as a first step the sample is illuminated causing material to be desorbed therefrom. In general the illumination step is effected by a short pulse of laser radiation having a duration of 0.5-200 nano-

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seconds and directed at an illumination spot with a diameter between approximately ten micrometers and several hundred micrometers, and an irradiance in the range of 10^6 watts/square centimeter or more to form a plume of desorbed and ionized material. As noted above, this desorbed material initially has a directional momentum imparted to it by the physical processes of laser-induced desorption. In accordance with the present invention a second step confines this desorbed material for a period such that the directional momentum is at least partially thermalized, i.e., randomized in direction and reduced in overall magnitude, by undergoing internal collisions and collisions with the surroundings before being subjected to spectrometric separation. It is understood that the plume itself is of small dimension, and the confinement is of corresponding dimension, for example, with a wall spacing such that analyte molecules in the plume undergo at least one collision with a surrounding wall or obstruction. The invention also contemplates that the thermalization may be accomplished using a two stage ion extraction in which low field strength is provided in an initial region to result in an extended residence time near the initial site of the plume before acceleration.

[0035] In general the invention may be practiced with either transmission or top illumination geometries, although different factors enter into consideration for positioning the actual containment and acceleration structures in relation to the substrate. Representative physical embodiments of the invention will be described below, with particular reference to a time of flight mass analysis instrument. However as will be apparent from the general description, the invention serves equally well and provides significant improvements when operated as the sample input for various other analysis instruments such as an ion trap, and ion cyclotron resonance Fourier transform mass spectrometer, and other instruments used to detect or characterize ions at low pressure.

[0036] FIGS. 3A and 3B illustrate a basic embodiment of the present invention, with the elements corresponding to those of FIG. 1 numbered correspondingly. As shown in FIG. 3A, an optical fiber 10 which may, for example, have a core of 140 or 200 micrometers in diameter, is butted up against one face of a transparent substrate 3 upon which a sample 2 comprised of a matrix with the analyte therein is deposited. Here a dried matrix is illustrated. The fiber 10 illuminates the sample 2 with its divergent output beam 1 causing a plume of desorbed material to emanate therefrom. As further shown in FIG. 3A, a containment structure 20 forms a compartment 21 about the plume having one or more exit apertures 22 in a wall thereof. The dimensions of the compartment 21 are comparable to that of the illumination spot e.g. 10 to 500 micrometers, and may be of the same order of magnitude of the extent of plume, such that the plume expands to fill the compartment within a few hundred nanoseconds.

[0037] The configuration shown in FIGS. 3A and 3B are both transmission illumination configurations in that the laser light illuminates the sample from a direction opposite to the ion extraction direction. In the configuration of FIG. 3A the sample is placed directly on the transparent substrate such that the fiber illuminates the sample from the bottom side, i.e. the side facing the substrate. As a result the material is desorbed from the bottom side of the sample; the sample 2 may for example consist of microcrystals in a layer several micrometers thick on a substrate and the plume may consist largely of material which has been desorbed from the bottom (substrate-facing) side of the crystals and which has turned around before forming the main body of the projecting plume.

[0038] FIG. 3B shows a corresponding configuration of this embodiment for reflection MALDI. In this embodiment, the sample 2 is deposited not on the substrate 3 separating the fiber and analysis chamber, but on a wall 20 of the enclosure. The fiber 10 then shines its beam through the substrate and across a small gap constituting the compartment to the sample on the far side. In either case, the plume expands into the compartmentalized space 21.

[0039] FIGS. 4A and 4B illustrate the subsequent evolution of the plume over time. As discussed above, the velocity of molecules in the plume may initially be on the order of several hundred meters per second or more. As shown in FIG. 4A, the plume evolves to fill the compartment 21 and in general to undergo internal collisions among matrix molecules and between matrix and analyte molecules as well as with the walls 20 of the specimen holder. This results in a randomization of the directions of movement of the molecules, and in the case of molecules having various degrees of freedom beyond the three orthogonal translational modes, as is typically the case for proteins and large organic molecules, the energy may also be partitioned internally to result in a substantially lower average velocity with a well behaved Maxwellian distribution. As shown in FIG. 4A, the molecules reach the exit apertures 22 after a relatively short diffusion time. FIG. 4B then shows the plume material accelerated from the apertures upon the application of an electric extraction field E_{ext}. Thus the apertures 22 provide the sample through discrete openings of defined size with a velocity which has been at least partly randomized, and preferably fully randomized with a Maxwellian distribution and a low mean velocity. This defined initial condition results in time of flight spectra having more sharply defined peaks and less spreading, resulting in a calculated mass resolution which is not only several times higher than conventional instruments, but can be independent of mass, resulting in a substantial improvement in spectral definition at high molecular weights.

[0040] FIGS. 5A and 5B illustrate a second embodiment 30 of the present invention in which a single body of novel construction has replaced the substrate and compartment of the first embodiment. Here, a high aspect capillary 32 is held by an electrically conducting housing or jacket 9, which serves for example to provide a uniform and field flattening conductive starting plane for the spectrometric acceleration. The sample 2 is deposited on inside walls of the capillary, which in turn surrounds the end of fiber 10 so that the output beam diverging from the fiber end irradiates the sample 2 and causes a plume of material to be ejected from the sides of the capillary into the central lumen 33. In this case, if the sample 2 is coated as a band around the interior of the capillary, the resultant plume is self-interfering, i.e. the highly directional desorption plume is aimed radially inward so that material from different portions of the wall collides with plume material from other portions resulting in a high incidence of collision within the small capillary volume 33. As further shown in FIG. 5B, the extraction electric field results in acceleration of a thermalized sample of material 35 along a direction transverse to the capillary axis into the analysis instrumentation.

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[0041]   The confinement geometry shown in **FIG. 5A** can also be used in a top illumination arrangement. In that case the laser beam emerging from the fiber **10** is preferably replaced by a focused or small diameter laser beam entering the confinement from the front (i.e. facing the mass analyzer) side.

[0042]   As is apparent from the foregoing example, the confinement of the plume need not amount to a total enclosure, but need only include an arrangement which assures collisional interaction of the desorbed material, preferably including at least one collision with a wall of a physical confining structure, which may for example change the direction of molecular travel and thus more quickly reduce the highly directional momentum by collisions among molecules of the desorbed material.

[0043]   **FIGS. 6A and 6B** illustrate another confinement arrangement, which in this case is configured for top side (i.e. the side of ion extraction) illumination. As before the numerals 1, 2, 3 and 4 designate respectively the laser illumination beam, the sample, the substrate holding the sample and the plume emitted by desorption from the sample. In this embodiment, a structure **40** provides a barrier or overhang **42** across the emission path of the plume. Overhang **42** may for example consist of a shelf or cap held by a support or post **41**. Overhang **42** does not entirely cover the sample **2**, but extends like a lean-to with an open sector **43** allowing oblique illumination by the laser beam **1**, focused to a small spot on the sample. As shown in **FIG. 6B** the plume then thermalizes under the lean to and is accelerated out through the sector **43**, to provide slow ions to the analysis instrument, which traps or accelerates them from that point outward.

[0044]   In all embodiments for a plume thermalization such as the examples shown in FIGS. **3** to **6**, the ion extraction may be accomplished by implementing several retarding and acceleration electric fields generated by suitable electrodes and/or meshes in the space between the plume confinement structures and the mass analyzer. One such mesh **80** at a potential U relative to the confinement is drawn in **FIG. 3A** by way of illustration. All potentials of the retarding or extraction electrodes may be time modulated, e.g. time delayed.

[0045]   While the foregoing arrangements have shown physical barriers in which an external structure such as a cap, cover or enclosure provides the thermalizing container, the invention further contemplates that the containment may result from more open structures implemented in part by the matrix itself. **FIGS. 7 and 7A** illustrate an experimental set up wherein thermalization has been observed to occur in a transmission mode illumination geometry due to partially thermalizing conditions provided by a bed of microcrystals of matrix material. In this apparatus **50**, a laser source was set up to provide illumination to a first fiber F_1 for top illumination of the sample, or a second fiber F_2 for transmission illumination from the backside of the sample. The sample was held on a substrate **3** with the fiber F_2 carried by a stage with its end face positioned exactly on the axis of the mass analyzer. The emerging laser beam aims at a selected position on the sample which was controlled by the stage carriage. As best seen in **FIG. 7A**, the sample **2** consisted of a relatively thin bed of microcrystals having a maximum size in the range of a few to a few hundred micrometers

deposited on the surface of the substrate facing the analysis chamber. In this case it was found that a substantial portion of the plume was emitted from the rear face of the crystals, i.e. the crystal faces the substrate and fiber, across a gap of no more than 5 micrometers, so that the emitted material quickly collided with the substrate and turned around to interact with plume material and result in a partially thermalized state of the desorbed material reaching the analysis instrument. The microcrystals lay in a random geometry, with rear faces lying a varying oblique angles so that the overall desorption momentum was initially less directional than for a top-illumination set-up, and quickly randomized further as the molecules collided and turned back into the flux of desorbed plume material.

[0046]   As further shown in **FIG. 7A**, the stage **60** includes a metal plate **61** which provided a substantially flat field about the substrate **3** for enhanced emission and acceleration geometry. The illumination fiber F_2 passes through a slot in this planar electrode, and butts against the substrate **3**. The fiber had a high numerical aperture and provided a substantially homogeneous beam profile of defined diameter at the sample. In the illustrated embodiment, a 141 μm fiber was used such that the butt coupled geometry provided a 200 micrometer spot on the sample. As further shown in **FIG. 7A**, the sample consisted of a typical drying deposit of microcrystals and macrocrystals on a simple glass cover sheet. The larger crystals were approximately 100 μm in dimension while the remaining microcrystals were much smaller and were completely removed by the initial actuations of the laser. The macrocrystals themselves naturally oriented with the substrate faces at an assortment of angles so that the plume emitted at substantially normal incidence from these surfaces would quickly collide with the substrate, heading off in a direction generally away from the substrate and back into the plume material, quickly undergoing thermalization.

[0047]   Skipping ahead briefly to **FIGS. 9A and 9B**, there is shown yet a fourth embodiment **70** of the invention, wherein containment, or more accurately, enhanced collisional interaction is provided by a porous or permeable structure. In this embodiment **70**, the sample **2** is placed on a substrate **3**, and covered with a shroud or sheath of porous or fibrous material **71** mounted above the sample with a suitable spacer **72**. Thermalization of the plume then occurs upon extraction of the ions through the porous or fibrous sheath, with or without an applied electric field which may be provided by suitable electrodes. In a typical set up, the sheath **71** is thin, for example 100 μm or less, and the spacer **72** provides a free distance of the order of the sample thickness. By way of example, a pulp-based fibrous paper similar to a laboratory filter paper was found to thermalize the emitted plume, although in general the material for this layer will be selected to neither react with nor contaminate the plume.

[0048]   In the embodiment shown in **FIG. 9A**, the sample is illuminated through the optically transparent substrate **3** in transmission geometry by a fiber **10** as described above. In the embodiment shown in **FIG. 9B** the sample is illuminated by a focused collimated light beam **1** in top illumination geometry through the porous or fibrous sheath **71** which is optically transparent or translucent. Suitable materials for the fibrous or porous sheath **71** include glass, ceramic and polymeric materials. A glass frit of a polymer or paper

micropore membrane as used for cleaning or purifying liquids such as water is also suitable for the sheath **71**. In an alternative embodiment (not illustrated) the sample can be placed directly onto the bottom side of the porous material, i.e., the side facing away from the mass analyzer. In another variation of this embodiment, the sample is incorporated into an optically transparent or translucent sheath of the porous material, and is illuminated in situ so that desorption occurs directly into the collision-enhancing porous structure of the sheath.

[0049] The foregoing examples show thermalization with various structures and bodies to illustrate a range of implementations of the invention, and these have involved simple mechanical elements. However it is not necessary to build up the thermalizing plume stage out of existing structures such as screens or capillary tubes. It is also possible to devise completely new structures for holding a sample to cause emission into a localized thermalizing environment. Thus for example the substrate **2** may consist of a plate having a plurality of thin needle-like projections or deep wells at its instrument-facing surface onto which the sample **2** is coated. In this case, the illumination **1** provided by the laser causes desorption from the sides of the pins, or from the walls of the wells, into a space confined by the surrounding walls or adjacent pins. The initial plume velocity then is substantially parallel to the general plane of the substrate and results in containment with a high collisional incidence, and subsequent emission of thermalized plume material across a plane normal thereto, at the ends of the pins or wells formed on the substrate. Such pins or wells may be formed as microstructures by known techniques of microlithography using compatible materials, and may for example be configured to additionally act as sample combs (e.g., hedgehog combs) or microtiter plates, allowing the support from a previous preparation process to serve as the substrate in a MALDI analyzer. Other novel microlithographic constructions will be readily implemented to provide an effective collision space for modulating the plume. Thermalization may be further improved by provision of a "collision buffer gas" to the confined, desorbed material. Preferably, the collision buffer gas promotes collisional dissociation, chemical ionization and/or molecule-molecule or ion-molecule reaction with the analyte.

[0050] A preferred embodiment of the invention is implemented with the substrate **3** carried on a stage **12** which is configured in conjunction with the fiber carrier to allow the fiber to illuminate any selected x, y position on the substrate **3** and desorb material therefrom. Such a stage is illustrated in **FIGS. 8A and 8B**. As shown in perspective view in **FIG. 8A**, the fiber **10** is mounted in a collar **10a** fixed to a plate **11** which provides a stable mechanical mounting to position the end of the fiber protruding from plate **11** into an opening **12a** in a stage plate **12**. The fiber end face is exactly centered in a fixed position on the axis of the mass analyzer so as to determine a symmetrical distribution of ions injected into the analyzer. The stage plate **12** is mounted inside the vacuum chamber for two dimension movement, e.g. by a conventional stage mounting and stepper drives, allowing illumination of any desired location of the sample or samples **2** on the substrate **3**. Preferably, the substrate **3** has a somewhat conductive and dielectric thin layer of material on its bottom (fiber facing) side, which electrically contacts

stage **12** and thus charges to an identical voltage as the stage, thereby providing a flat electrical field at the emission surface of the substrate **3**.

[0051] In another aspect, the invention features a process for nucleic acid sequencing by directly analyzing nucleic acids contained in a pin-tool by MALDI mass spectrometry. In a preferred embodiment, the nucleic acid obtained from the sample is initially amplified. For example, a PCR reaction can be performed to "master" mix without addition of the dideoxynucleotides (d/ddNTPs) or sequencing primers. Aliquots can then be isolated via a conjugation means and transferred, for example to a sequencing plate, where d/ddNTPs and primers can then be added to perform a sequencing reaction. Alternatively, the PCR can be split between A, C, G, and T master mixes. Aliquots can then be transferred to a sequencing plate and sequencing primers added.

[0052] For example, 0.4-0.5 pmol of PCR product can be used in a cyclesequencing reaction using standard conditions, allowing each PCR to be used for 10 sequencing reactions (1033 A, C, G, and T). The sequencing reactions can be carried out in a volume of 10 μl containing 5-6 pmol of 5'-labeled sequencing primer in a standard 384 microwell plate allowing up to 96 sequencing reactions (3360 bases at 35 bases per reaction). Alternatively, a 192 microwell plate approximately 5×5 cm in a 12×16 format can be used. This format allows up to 48 sequencing reactions to be carried out per well, resulting in 1680 bases per plate (at 35 bases per reaction). The format of the sequencing plate will determine the dimensions of the transfer agent (e.g., pin-tool).

[0053] A pin tool in a 4×4 array (**FIG. 10**) can be applied to the wells of the sequencing plate and the sequencing products captured, e.g., on functionalized beads, which are attached to the tips of the pins ($\geq$1 pmol capacity). During the capture/incubation step, the pins can be kept in motion (vertical, 1-2 mm travel) to mix the sequencing reaction and increase the efficiency of the capture.

[0054] Alternatively, the nucleic acid can be directly captured onto the pintool, for example, if an electrical field is applied, as shown in **FIG. 14**. When voltage is applied to the pintool, the nucleic acids are attracted towards the anode. This system also purifies nucleic acids, since uncharged molecules remain in solution and positively charged molecules are attracted to the cathode. For more specificity, the pin-tools (with or without voltage), can be modified to contain partially or fully single stranded oligonucleotides (e.g., about 5-12 base pairs in length). Only complementary nucleic acid sequences (e.g. in solution) can then be specifically conjugated to the pins.

[0055] In yet a further embodiment, a PCR primer can be conjugated to the tip of a pin-tool. PCR can be performed with the solid phase (pin-tool)-bound primer and a primer in solution, so that the PCR product becomes attached to the pin-tool. The pin-tool with the amplification product can then be removed from the reaction and analyzed (e.g., by mass spectrometry).

[0056] Examples of different pin conformations are shown in **FIG. 11**. For example, **FIGS. 11A, 11B** and **11C** show a solid pin configuration. **FIGS. 11D and 11E** show pins with a channel or hole through the center, for example to accommodate an optic fibre for mass spectrometer detection. The

pin can have a flat tip or any of a number of configurations, including nanowell, concave, convex, truncated conic or truncated pyramidal (e.g. size 4-800 μ across×100 μ depth). In a preferred embodiment, the individual pins are about 5 mm in length and about 1 mm in diameter. The pins and mounting plate can be made of polystyrene (e.g. one-piece injection moulded). Polystyrene is an ideal material to be functionalized and can be moulded with very high tolerances. The pins in a pin-tool apparatus may be collapsible (e.g., controlled by a scissor-like mechanism), so that pins may be brought into closer proximity, reducing the overall size.

[0057] For detection by mass spectrometry, the pin-tool can be withdrawn and washed several times, for example in ammonium citrate, to condition the sample before addition of matrix. For example, the pins can simply be dipped into matrix solution. The concentration of matrix can then be adjusted such that matrix solution only adheres to the very tip of the pin. Alternatively, the pin-tool can be inverted and the matrix solution sprayed onto the tip of each pin by a microdrop device. Further, the products can be cleaved from the pins, for example into a nanowell on a chip, prior to addition of matrix. For analysis directly from the pins, a stainless steel "mask" probe to further confine the plume can be fitted over the pins in one scheme (**FIG. 12**), which can then be installed in the mass spectrometer.

[0058] Two mass spectrometer geometries for accommodating the pin-tool apparatus are proposed in **FIG. 13**. The first accommodates solid pins. In effect, the laser ablates a layer of material from the surface of the crystals, the resultant ions being accelerated and focused through the ion optics. The second geometry accommodates fibre optic pins in which the samples are lasered from behind. In effect, the laser is focused onto the pin-tool back plate and into a short optical fibre (about 100 μm in diameter and about 7 mm length to include thickness of the back plate). This geometry requires the volatilized sample to go through the depth of the matrix/bead mix, slowing and cooling down the ions resulting in a type of delayed extraction which should actually increase the resolution of the analysis.

[0059] The probe through which the pins are fitted can also be of various geometries. For example, a large probe with multiple holes, one for each pin, fitted over the pin-tool. The entire assembly is translated in the X-Y axes in the mass spectrometer. Alternatively, as a fixed probe with a single hole, which is large enough to give an adequate electric field, but small enough to fit between the pins. The pin-tool is then translated in all three axes with each pin being introduced through the hole for sequential analyses. This format is more suitable for the larger pin-tool (i.e., based on a standard 384 well microplate format). The two probes described above, are both suitable for the two mass spectrometer geometries described above.

[0060] **FIG. 15** schematically depicts the steps involved in mass spectrometry sequencing by post biology capture as described above.

[0061] This completes a description of basic embodiments of the invention and representative constructions for implementing the improved laser desorption of the present invention. The invention being thus disclosed and described, further variations and modifications will occur to those skilled in the art and all such variations and modifications are considered to be within the scope of the invention, as defined by the claims appended hereto.

What is claimed is:

1. An apparatus for matrix assisted laser desorption of a large molecule analyte, such apparatus comprising a support stage including means for holding a sample on a substrate in a defined region of the stage an optical fiber having a first end adapted to couple to a light source for receiving a light input, and a second end held by said stage in a position to illuminate a spot region on the sample, the stage positioning the second end so that its output beam passes through the substrate to directly illuminate said spot region on the sample with a spot of defined size at a fluence effective to desorb the analyte from the sample, whereby the desorbed material has a directional momentum and the apparatus further comprises a means for confining said desorbed material sufficiently to at least partially thermalize said directional momentum.

2. An apparatus of claim 1, comprising a plurality of optical fibers in an array arranged to illuminate an array of separate spot regions of the sample, each fiber being separately actuable to desorb material from a respective spot region of the sample at a distinct time whereby plural samples of desorbed analyte may be provided at successive instants to a common mass analyzer.

3. An apparatus of claim 1, wherein the stage is operative to move the substrate with the sample in at least two lateral dimensions relative to the second end of the optical fiber for aiming at arbitrary locations on the sample to desorb material.

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